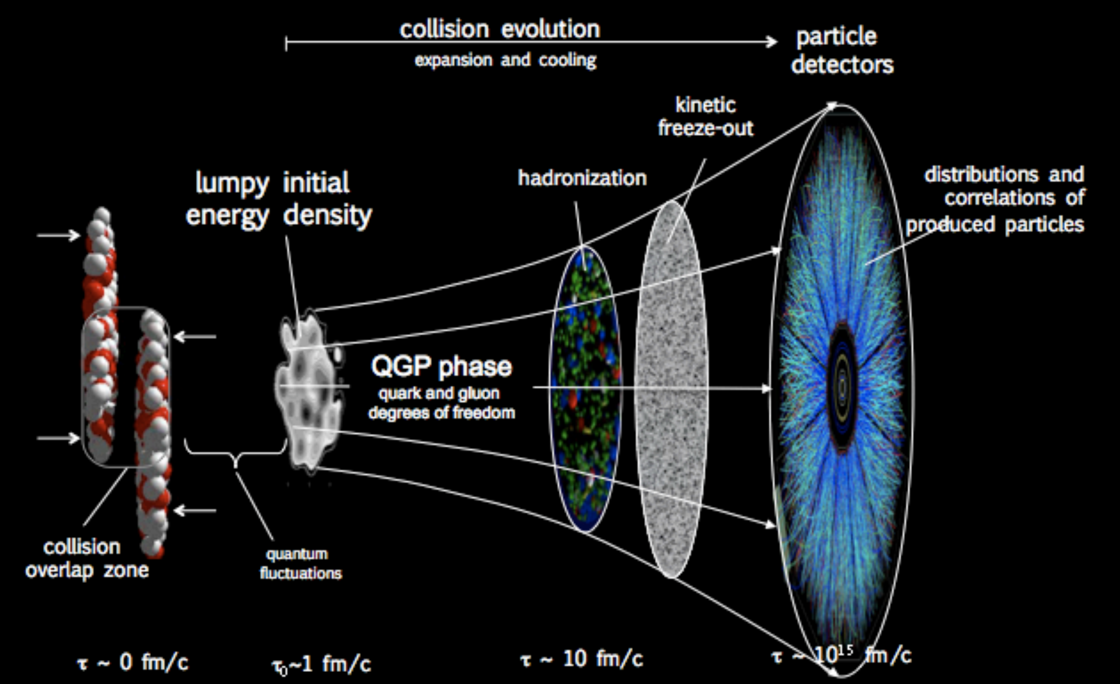
Non-flow and Fluctuations: A Systematic Error or a Killer Measurement?

Paul Sorensen

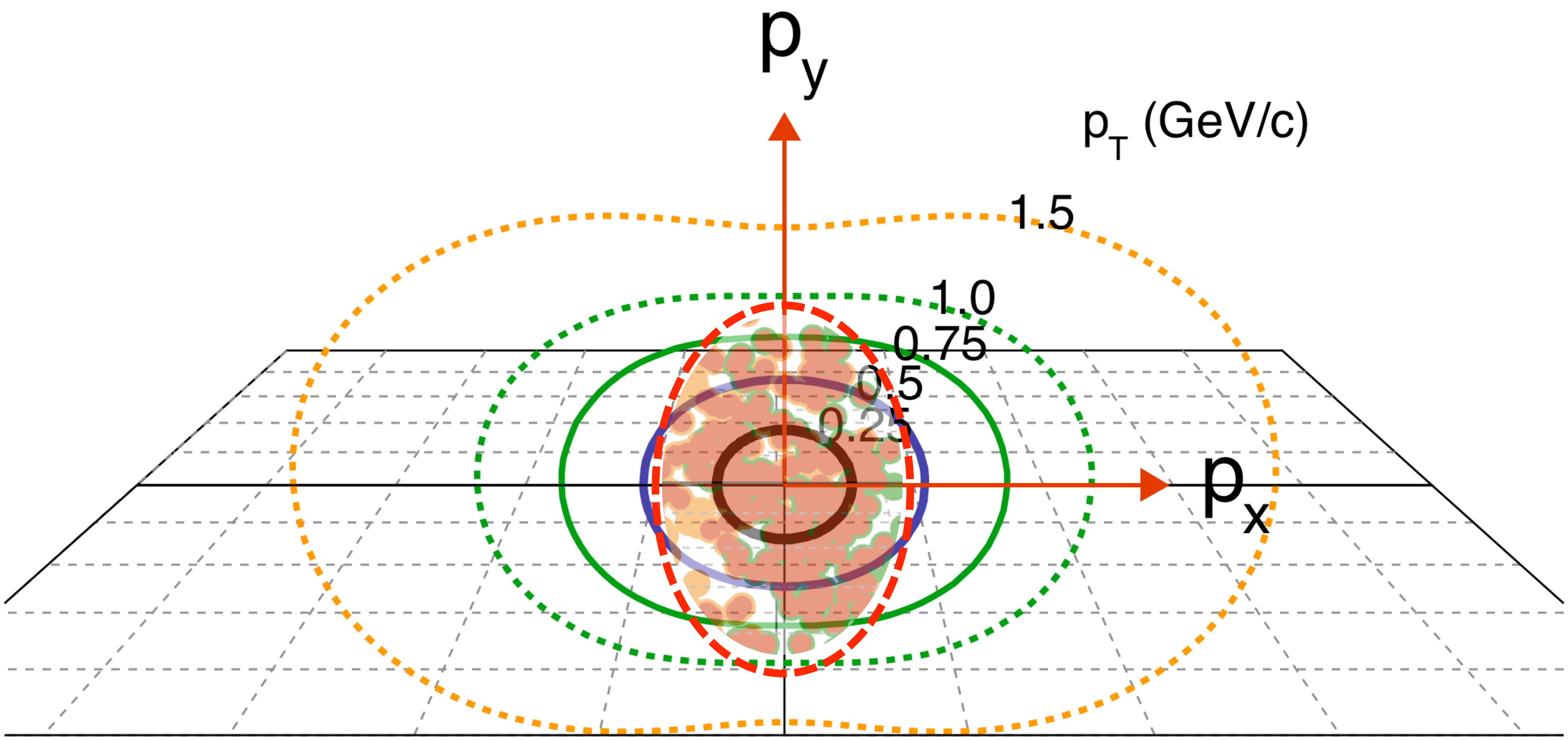
BROOKHAVEN NATIONAL LABORATORY



Elliptic Flow: A Study of Space-Momentum Correlations In Relativistic Nuclear Collisions.
P. Sorensen, Quark Gluon Plasma, Vol. 4, World Scientific, arXiv:0905.0174 [nucl-ex]

CATHIE/TECHQM Workshop

Azimuthal Distributions



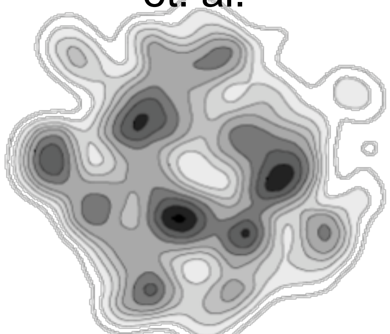
Are particles emitted at random angles?

No: they remember the initial geometry

Geometry Fluctuations

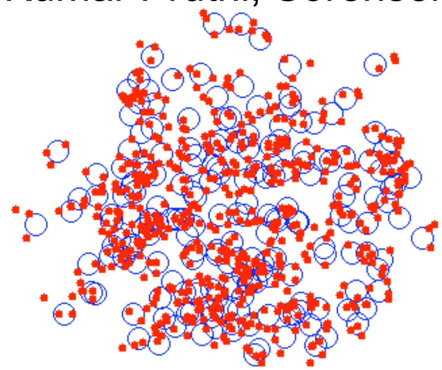
If we have space-momentum correlations, then there should be a lot more to the story than just <v_2>

Hama, Grasi, Kodama, et. al.



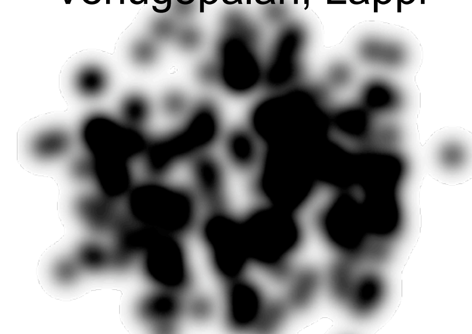
NexSPheRio

Kumar Pruthi, Sorensen



Additive Quark Model

Dumitru, Gelis, McLerran, Venugopalan, Lappi

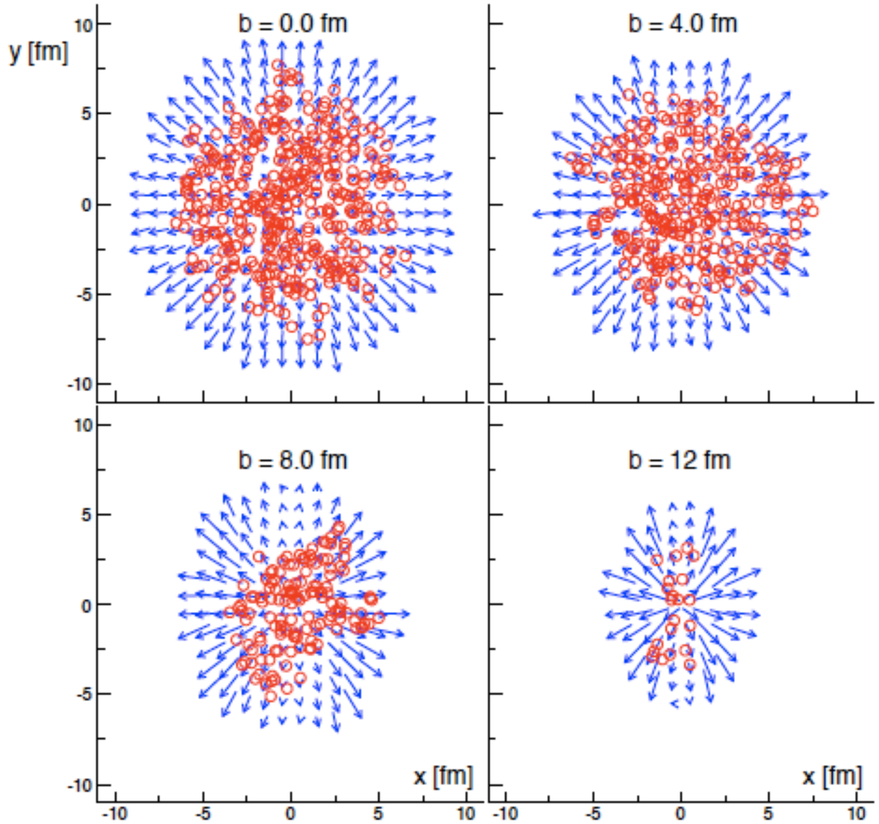


IPsat GCG, Glasma

H. Kowalski, T. Lappi and R. Venugopalan, Phys. Rev. Lett. **100**, 022303 [arXiv:0705.3047 [hep-ph]].

Can we get away with ignoring the rest? At what cost?
Can we take advantage of the initial geometry fluctuations?

Fluctuations



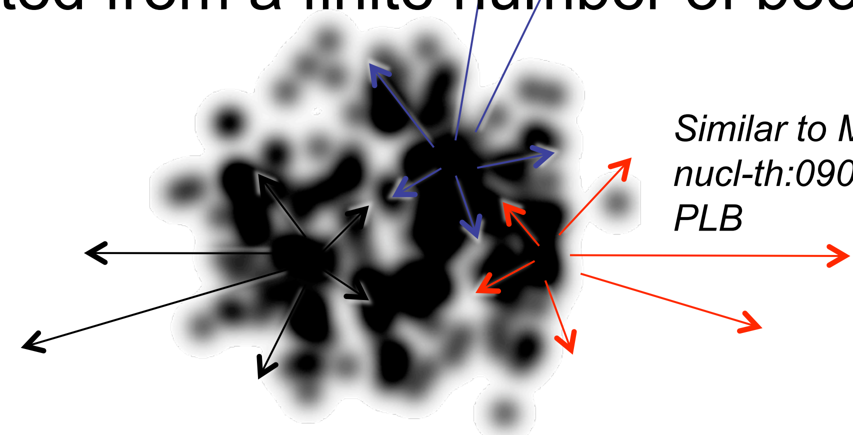
When we imagine v_2 is proportional to the initial eccentricity,

when we imagine ε fluctuations drive v_2 fluctuations (integral to concept of v_2/ε_{part}),

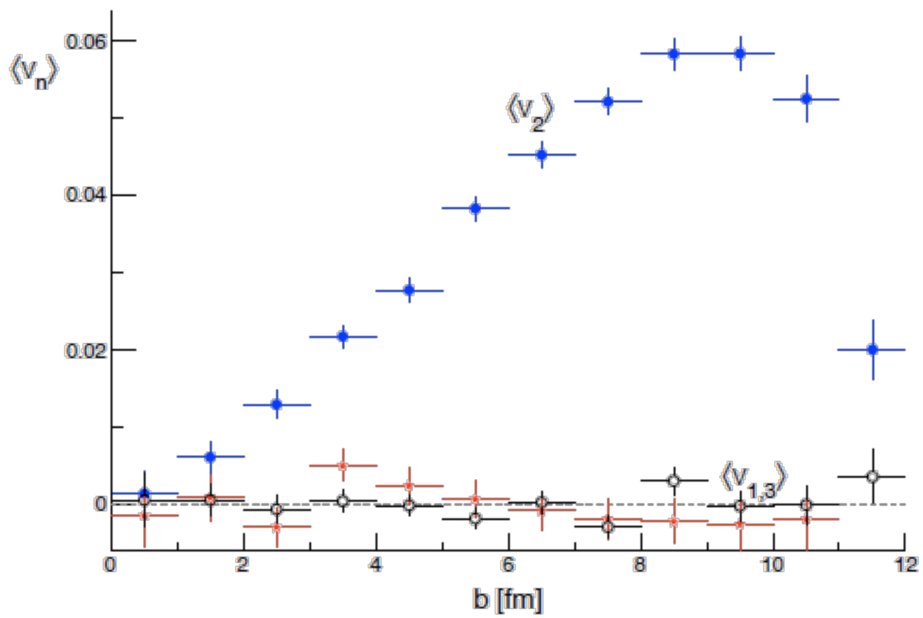
we can't escape the other consequences: large v_n fluctuations for n=1,2,3,4… and 2-particle correlations

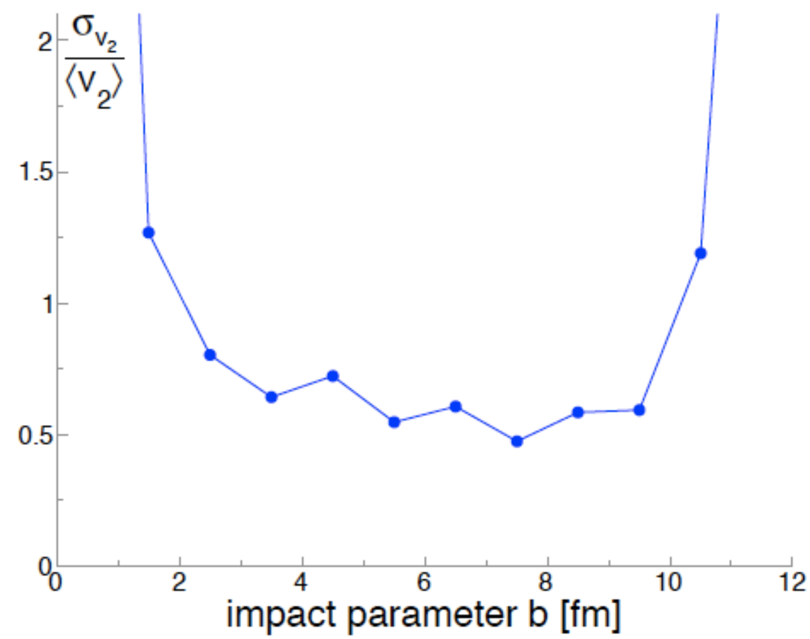
Boosted Hot-spots for Illustration Purposes

Particles emitted from a finite number of boosted space points

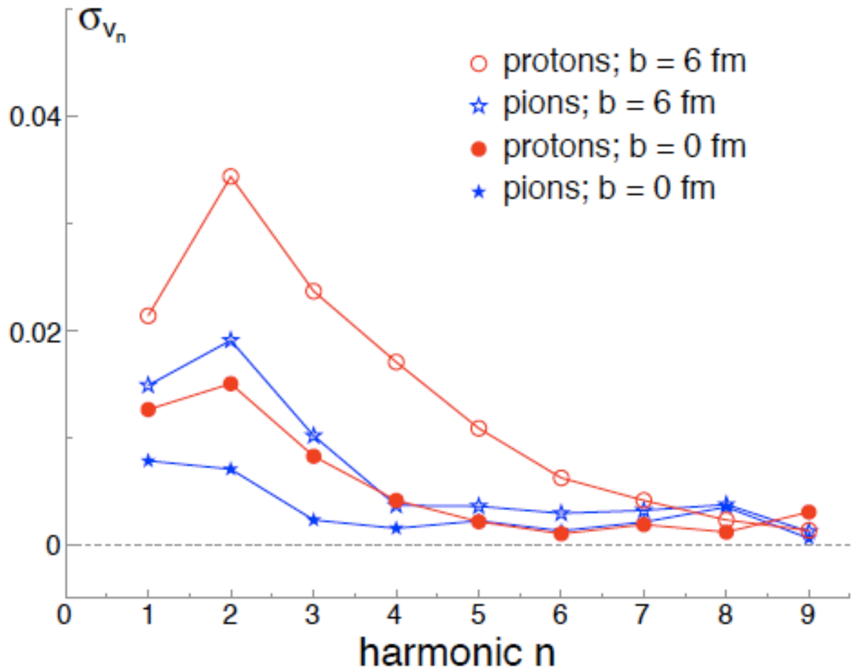


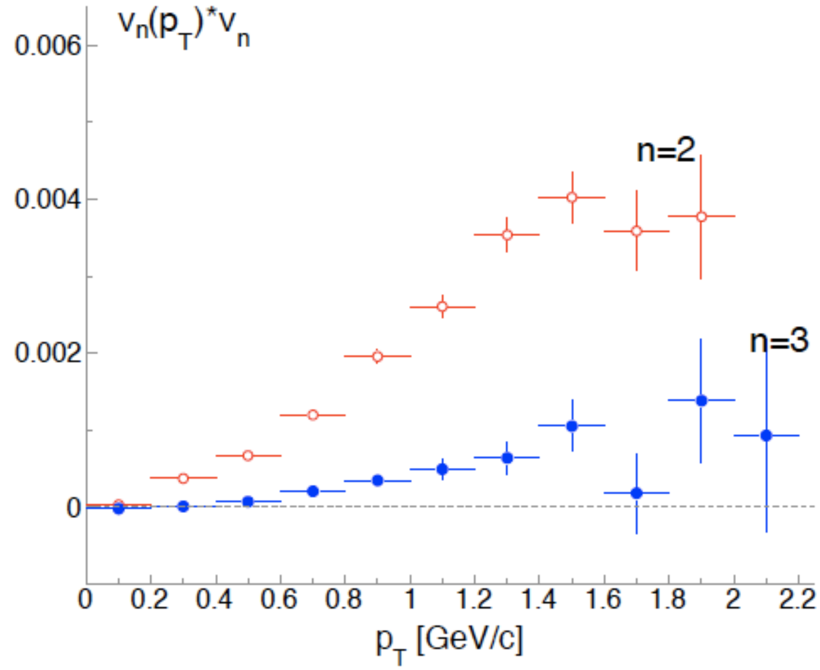
Similar to Mócsy, Sorensen: nucl-th:0908.3983 submitted to PLB





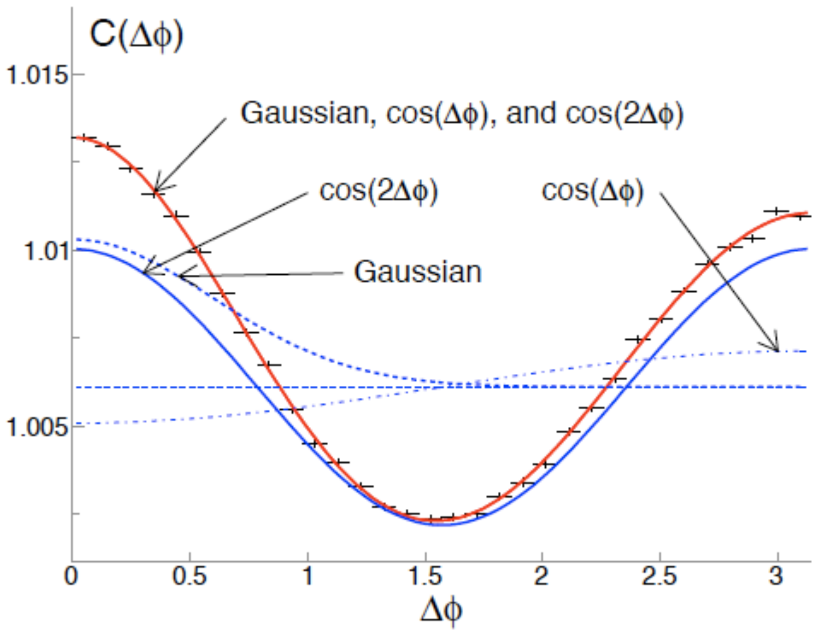
The v_n fluctuations vs n and p_T

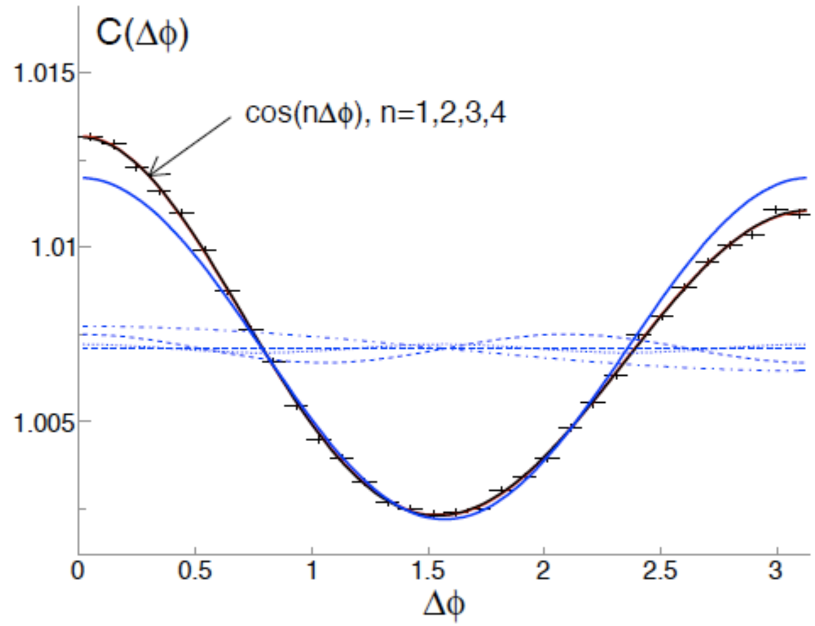




Toy monte-carlo captures v_2 and v_2 fluctuations and predicts v_n fluctuations for n=1,2,3,4…

Implies non-trivial 2-particle correlations





We can fit with ZYAM + jet ***or*** just cos(n) terms

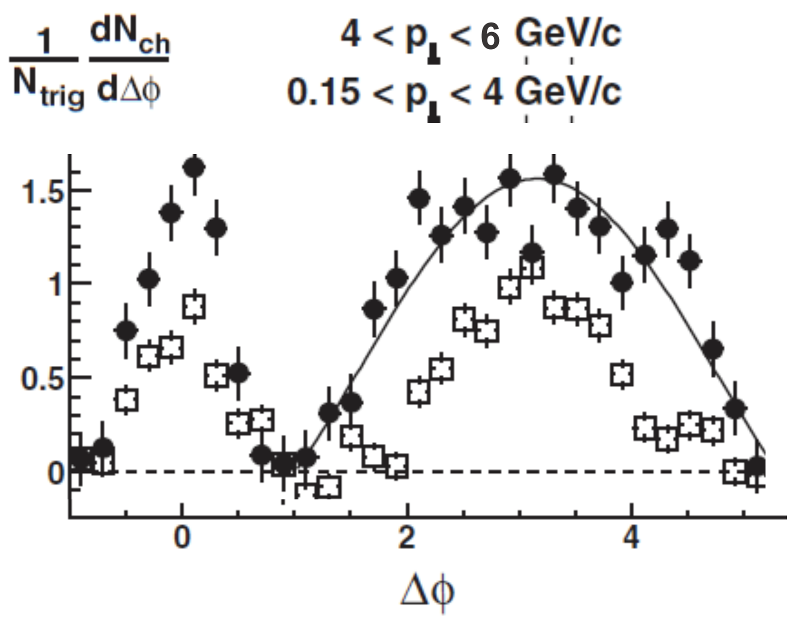
Allowing odd n terms in ZYAM will make it possible to fit the whole signal -> no jets or cones required

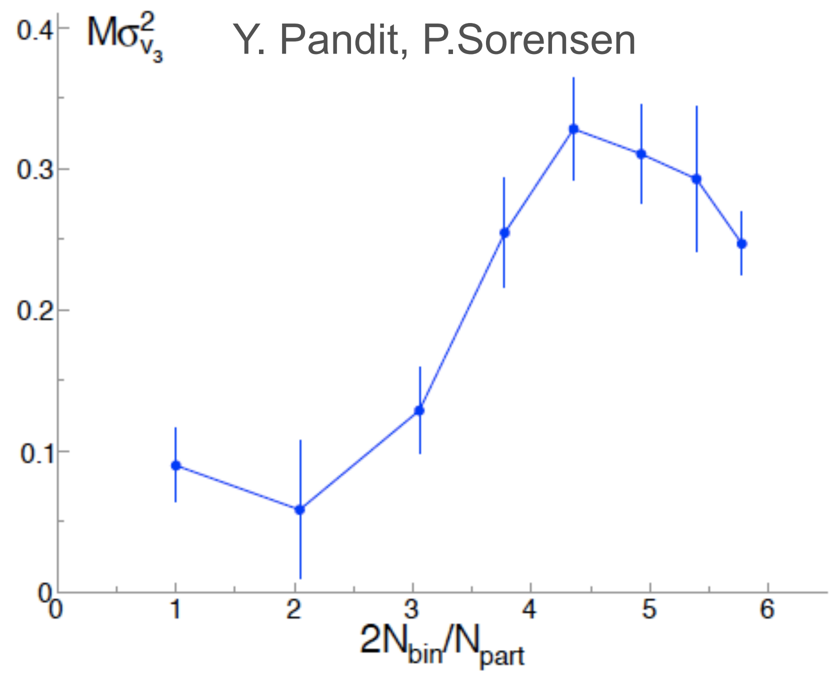
v_3 in data

$$\sigma^2_{v_n} = \langle v_n v_n \rangle - \langle v_n \rangle \langle v_n \rangle$$

$$\sigma^2_{v_3} = \langle v_3 v_3 \rangle - \langle v_3 \rangle \langle v_3 \rangle = \langle v_3 v_3 \rangle \neq 0$$

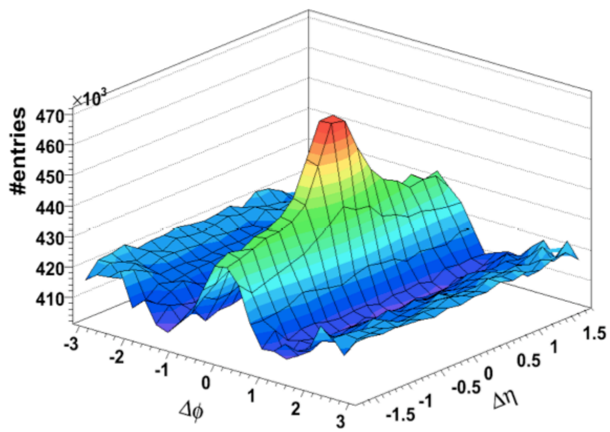
STAR PRL





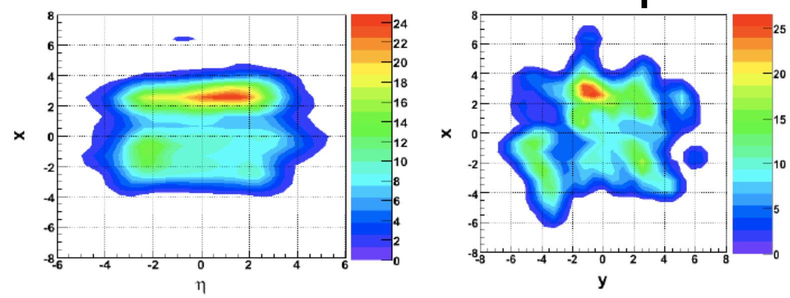
An Acoustic Expansion of Initial State Correlations and Fluctuations

➔Data🡐

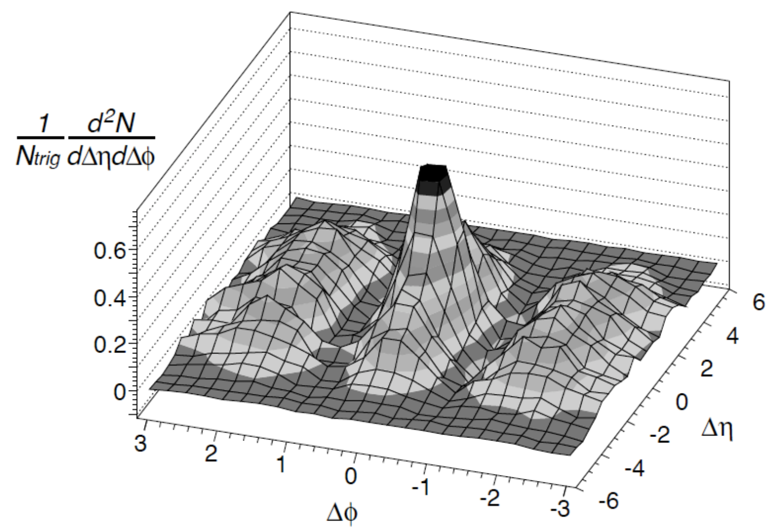


➔Model🡐

Initial State + Acoustic Expansion



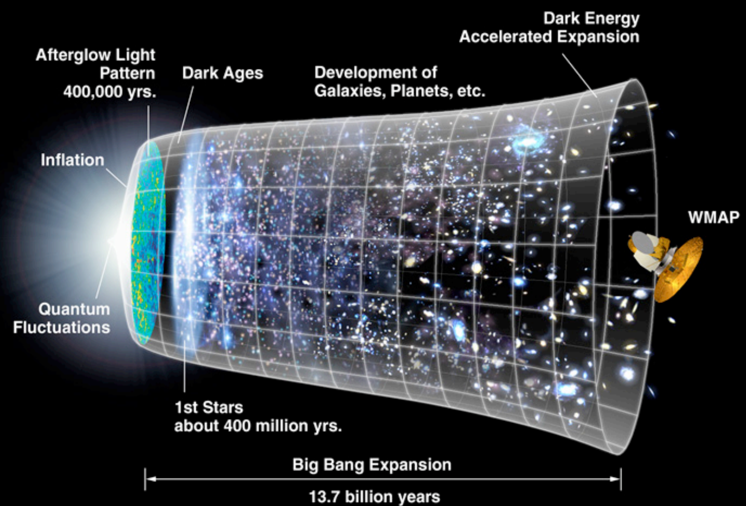
NexSPheRIO: J.Takahashi, B.M.Tavares, W.L.Qian, F.Grassi, Y.Hama, T.Kodama and N.X



Analogies with the early universe

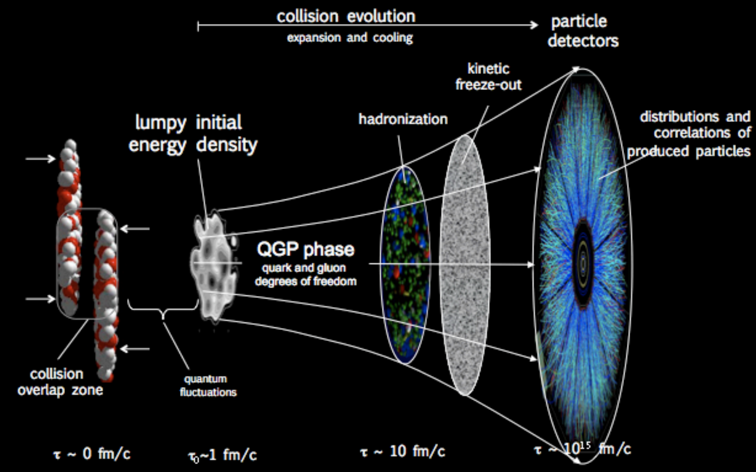
A rhyming game

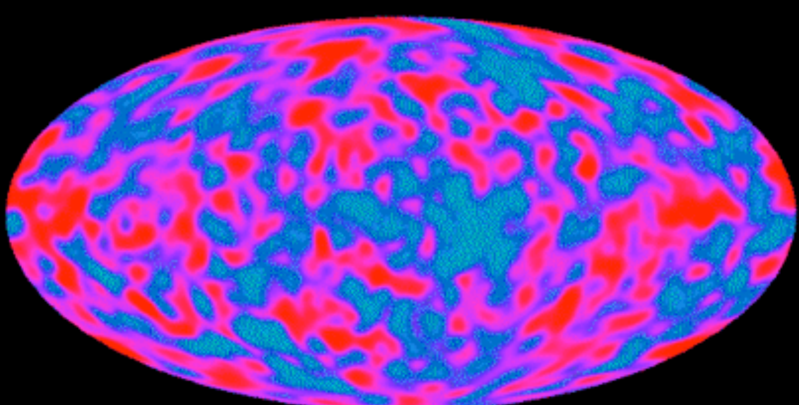
The Universe



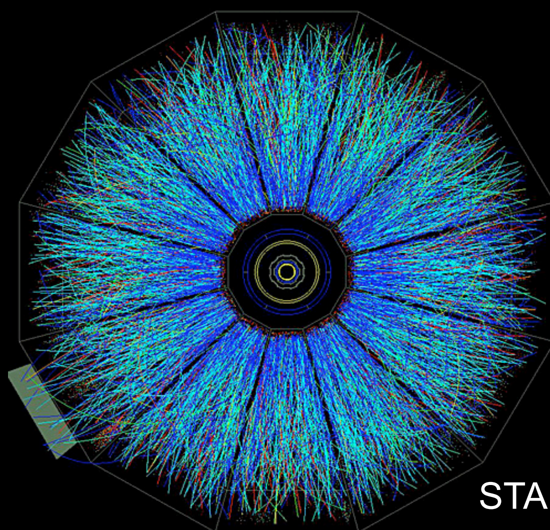
Credit: NASA

RHIC



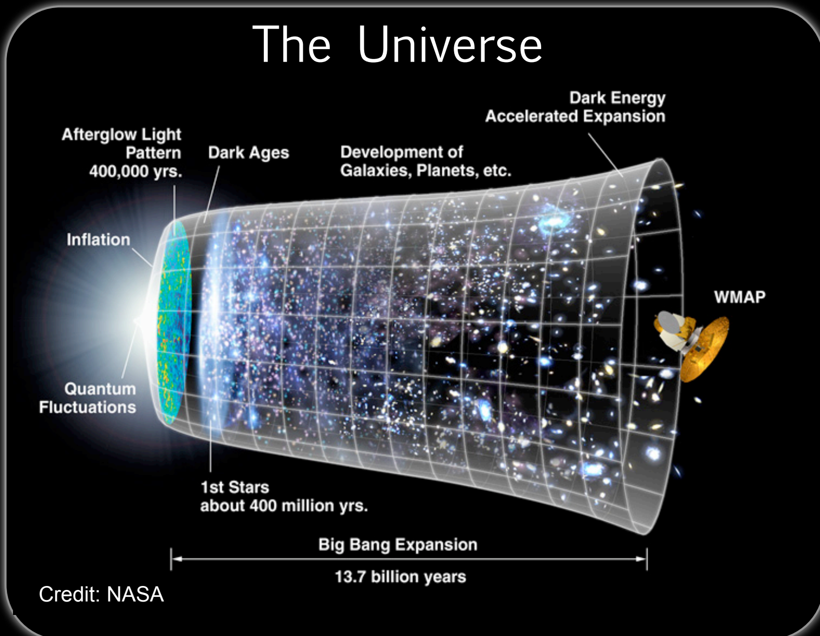


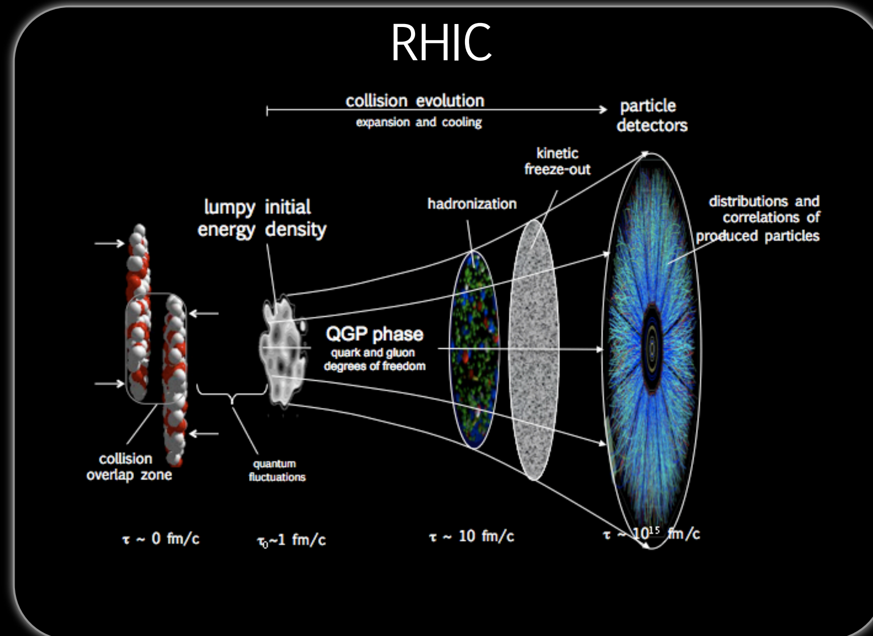
WMAP

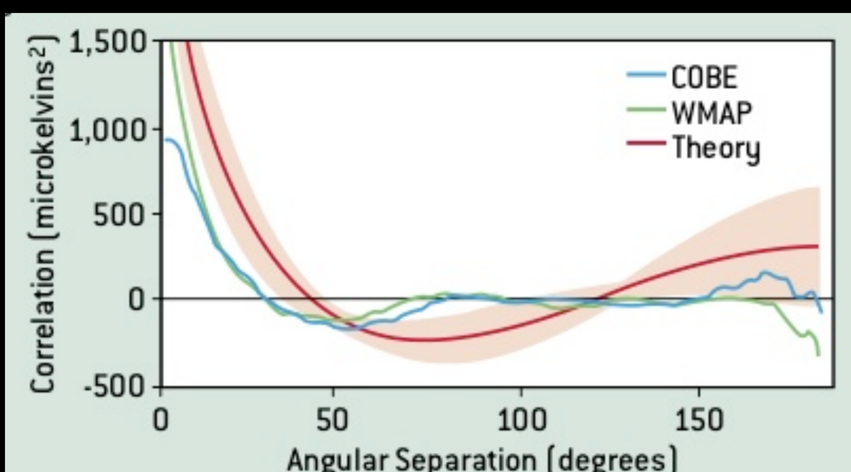


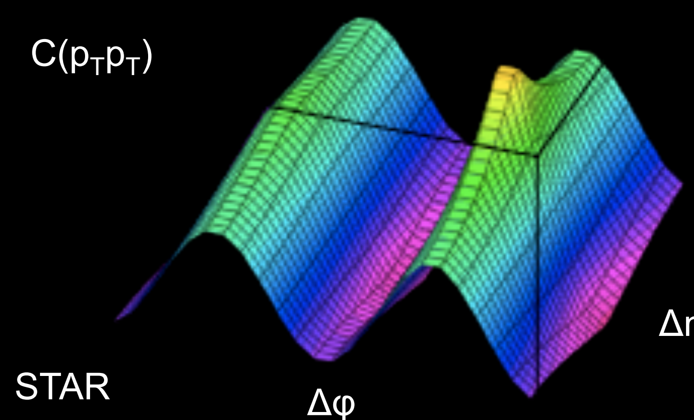
STAR

Analogies with the early universe



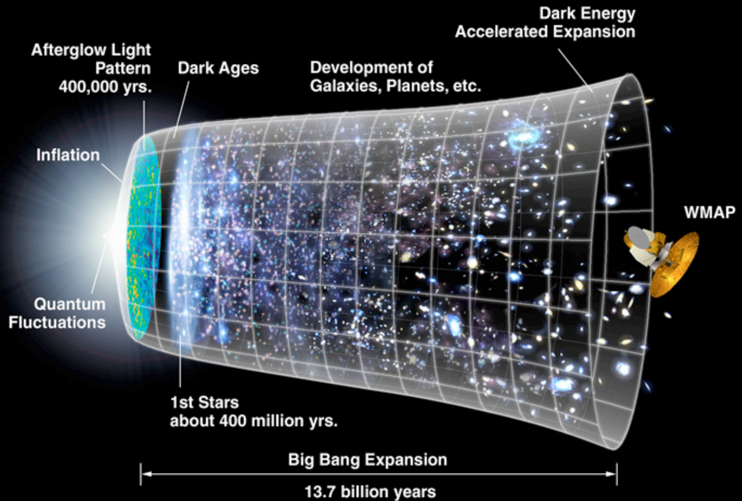






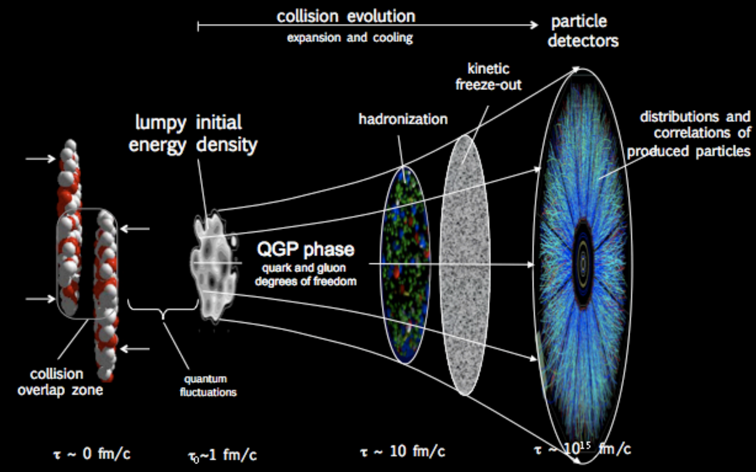
Analogies with the early universe

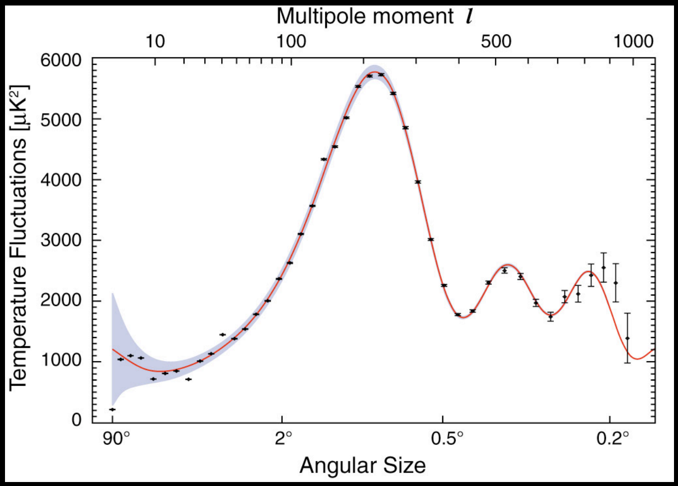
The Universe



Credit: NASA

RHIC





WMAP

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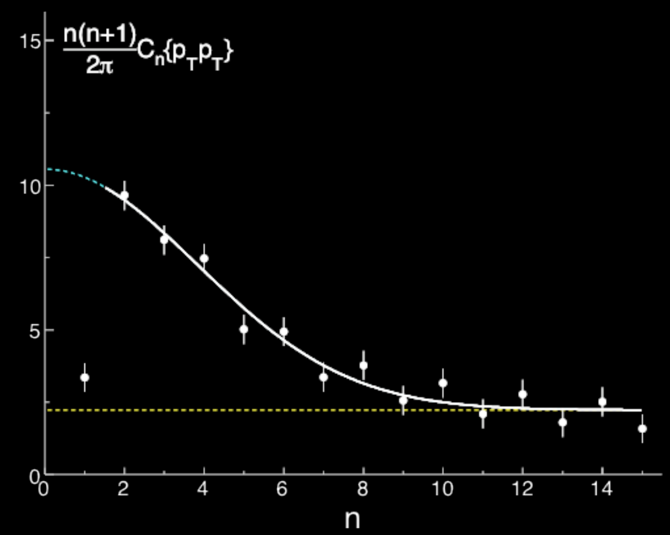


Back to "its not an error, its a measurement"

$$\sigma_{v_n}^2 = \langle v_n v_n \rangle - \langle v_n \rangle \langle v_n \rangle$$

$$v_2^2\{2\} = \langle \cos(2(\varphi_1 - \varphi_2)) \rangle = \langle v_2 \rangle^2 + \sigma_{v_2}^2 + \delta_{non-RP}$$

$$v_2^2\{4\} = \sqrt{2v_2^2 v_2^2 - v_2^4} \approx \langle v_2 \rangle^2 - \sigma_{v_2}^2$$

$$v_2^2\{2\} - v_2^2\{4\} \approx \underbrace{\delta + 2\sigma_{v_2}^2}$$

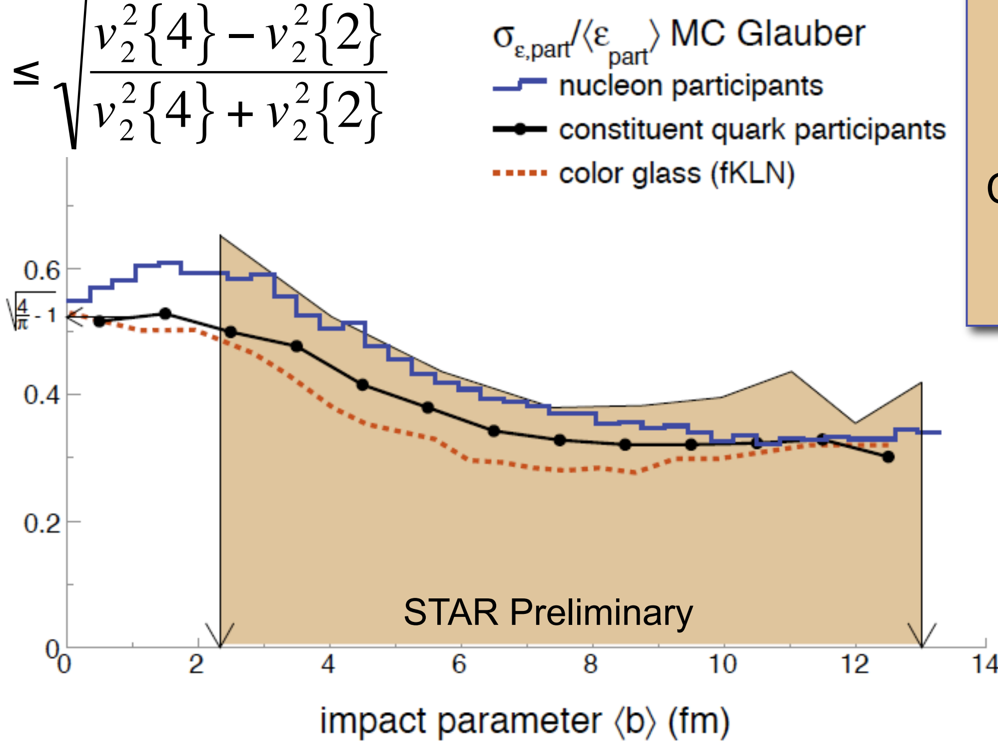
If our "standard model" describes the space-momentum correlations in heavy-ions, it should describe all/most of this term

Why? $v_2 \propto \varepsilon$ + eccentricity fluctuations has implications

Comparison to Models

Upper limit challenges models: MC Glauber already exhausts entire width with participant fluctuations

$$\frac{\sigma_{v_2}}{\langle v_2 \rangle} \leq \sqrt{\frac{v_2^2\{4\} - v_2^2\{2\}}{v_2^2\{4\} + v_2^2\{2\}}}$$



Additive Quark MC:
- treats confined constituent quarks as the participants
- decreases eccen. fluctuations

Color Glass MC:
- includes effects of saturation
- increases the mean eccentricity

comparison to hydro (NexSPheRio): *Hama et.al. arXiv:0711.4544*

eccentricity fluctuations from CGC: *Drescher, Nara. Phys.Rev.C76:041903,2007*

extraction of Knudsen number: *Vogel, Torrieri, Bleicher. nucl-th/0703031*

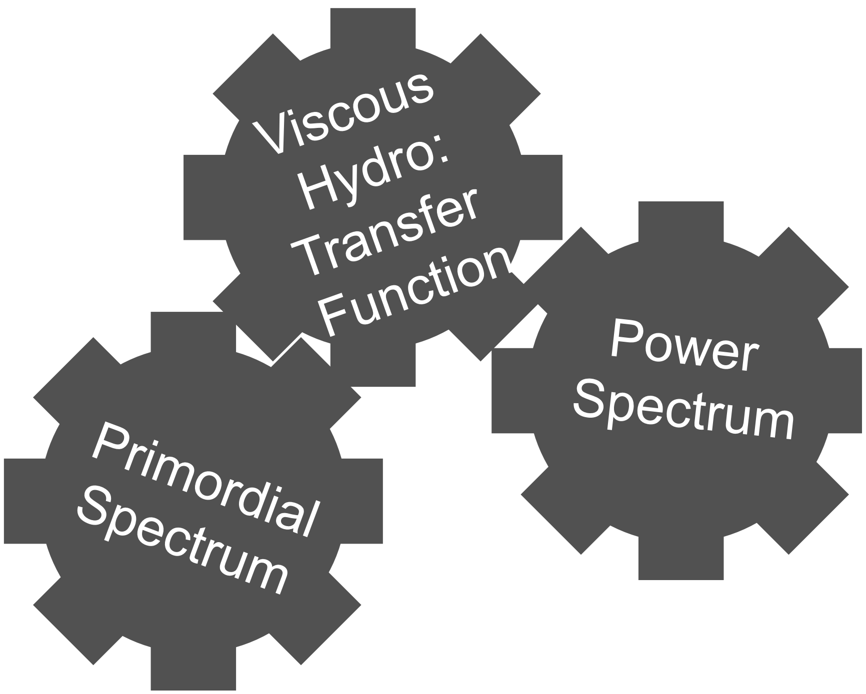
fluctuating initial conditions: *Broniowski, Bozek, Rybczynski. Phys.Rev.C76:054905,2007*

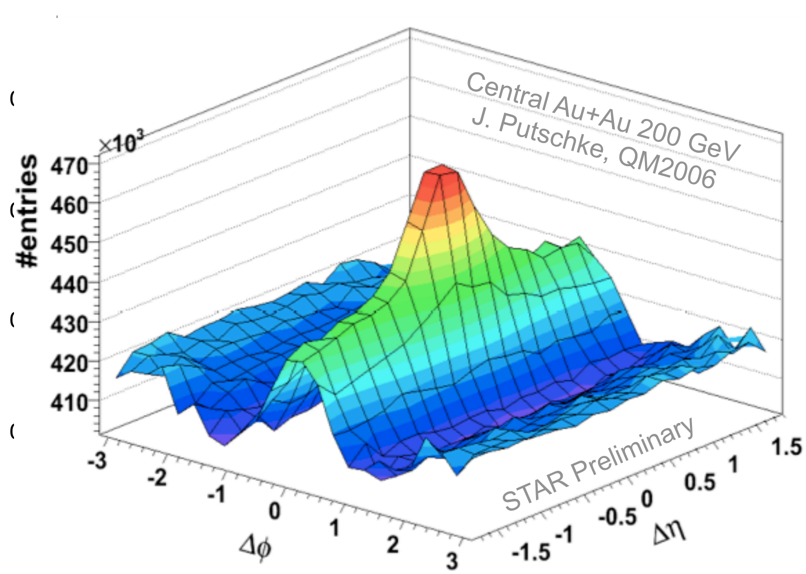
first disagreement with $\varepsilon_{\mathrm{standard}}$ and use of quark MC: *Miller, Snellings. nucl-ex/0312008*

A Modest Proposal

Calculate the primordial power spectrum

Turn the hydro crank: Compare to data





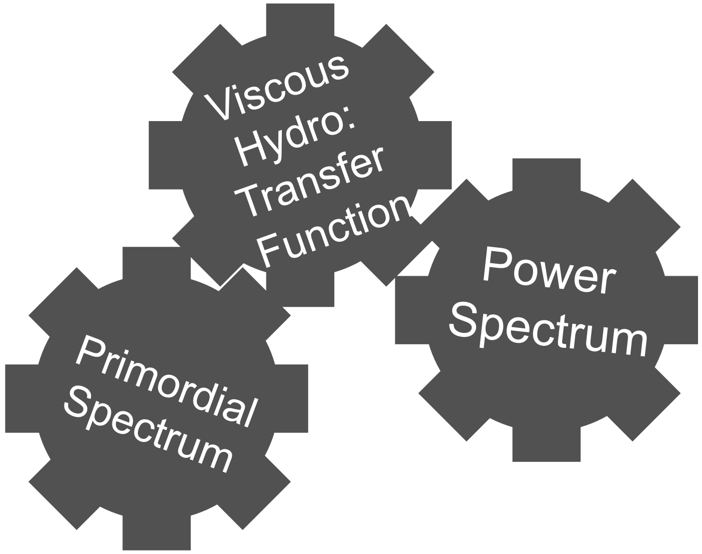
Summary

Strong space-momentum correlations are a prominent feature of heavy-ion collisions

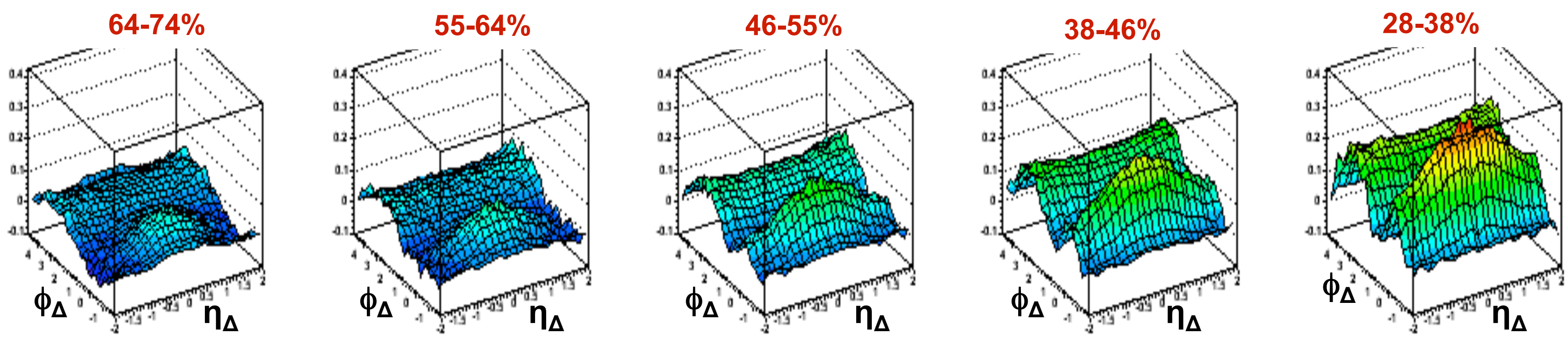
Large gradients and fluctuations are prominent in the data

Things like length-scales and gradients seem to be central to estimating eta/s

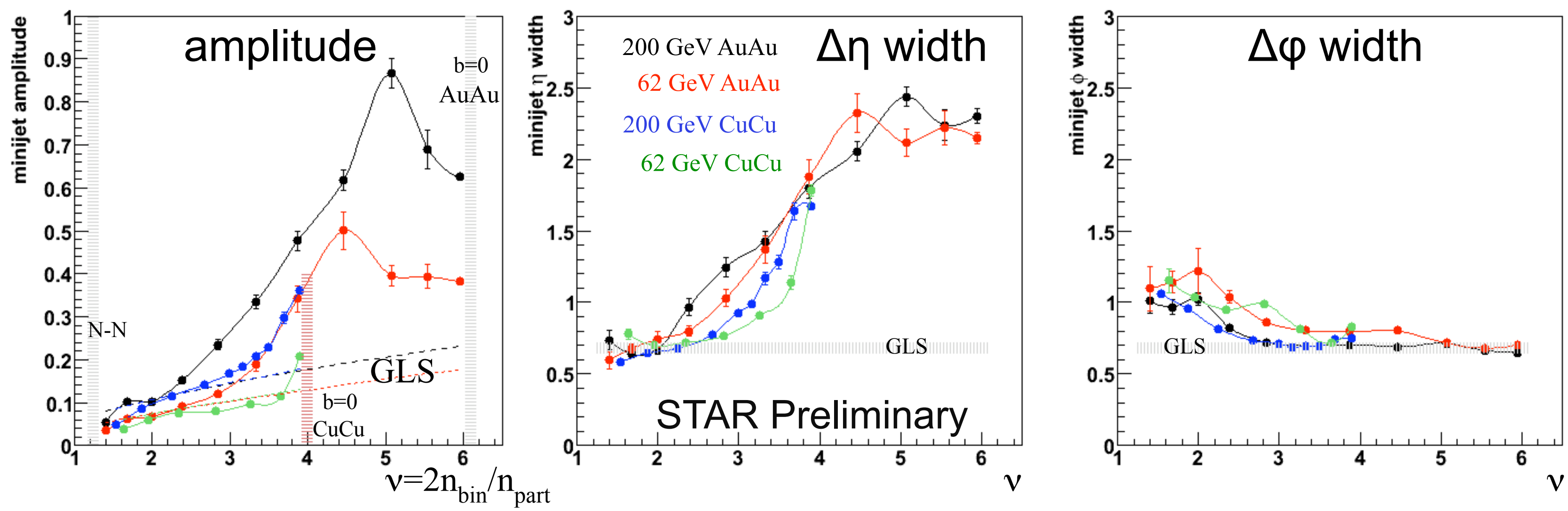
It would be nice to see if hydro really does make the connection



Flow Induced 2-Particle Correlations?



Correlations Between All Pairs: *HBT, and photon conversion pairs subtracted*



Yield grows faster than N_{bin} scaling; onset in peripheral A+A

Ridge and Cone Phenomenology

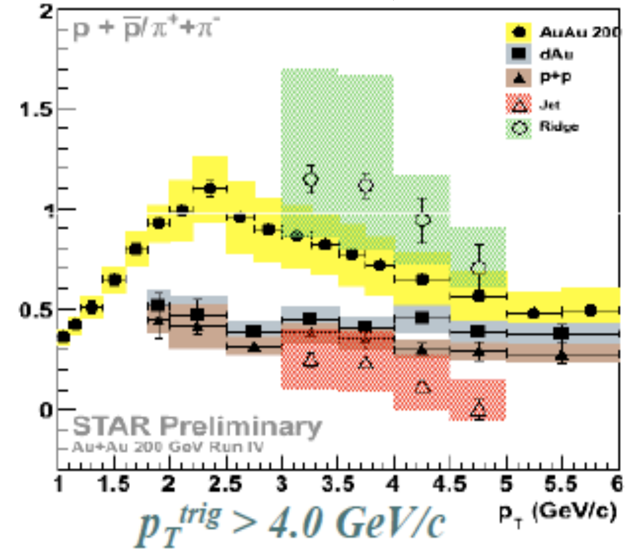
Chemical composition of the ridge & cone
- Baryon-to-Meson ratios like the bulk (p/π and K_S/Λ)

Correlation amplitude
- Correlations increase faster than N_{bin} or N_{part}; closer to M(M-1) instead
- Near and Away-side amplitudes have same centrality dependence

Longitudinal and Azimuthal Width
- both different from fragmentation

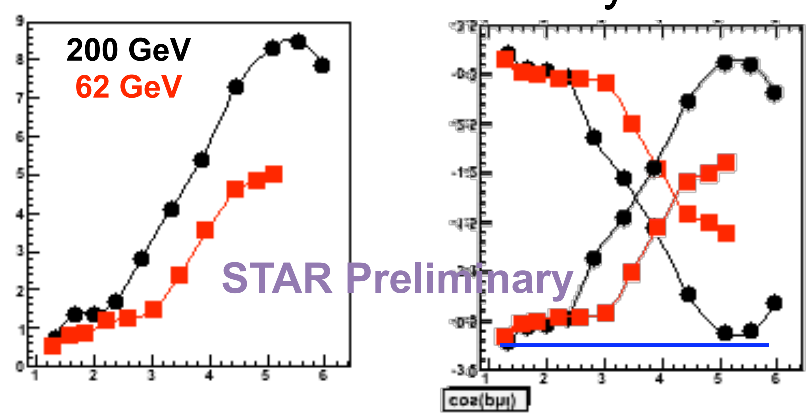
p_T spectra of the ridge and cone
- Both are soft; like the bulk not like jet fragments

Suarez: QM08



near side

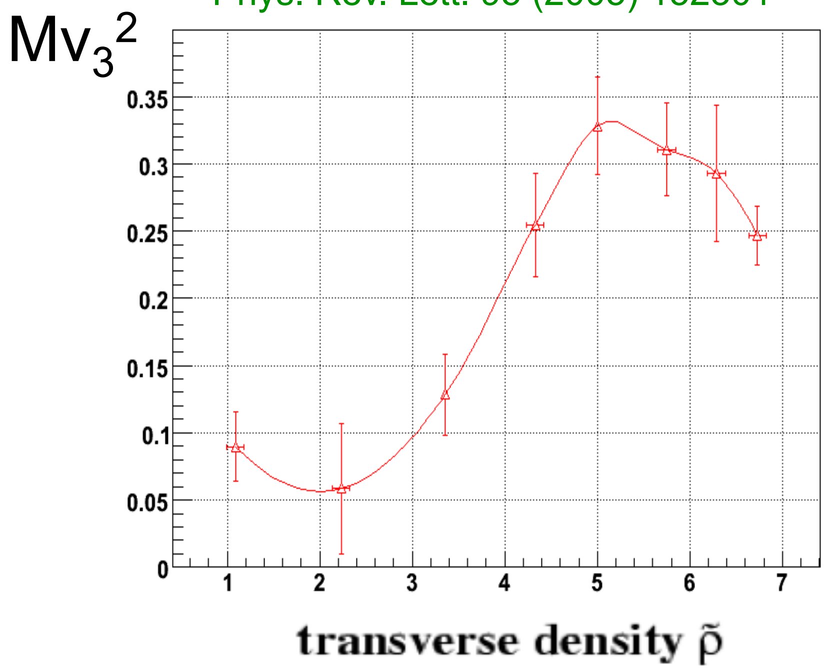
away side



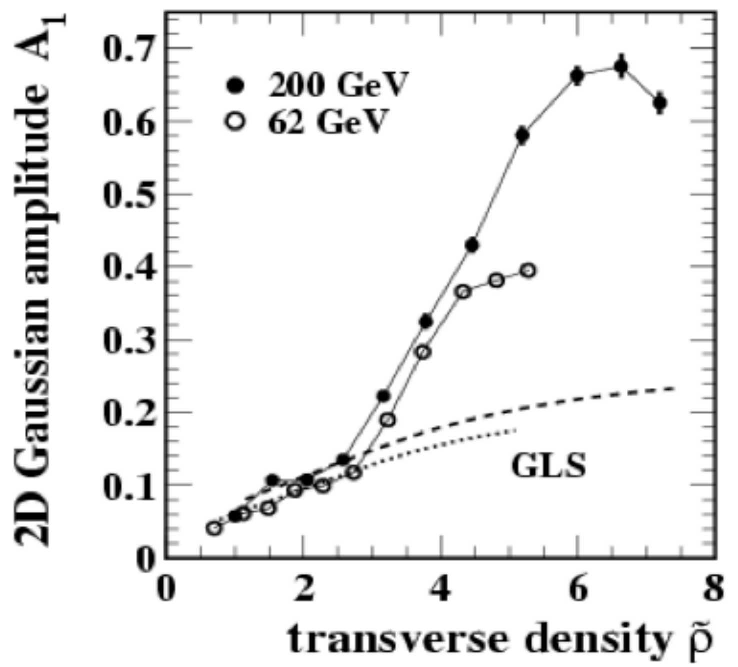
Lanny Ray: CATHIE RIKEN workshop

What's So Odd About the Ridge and Cone?

Y. Pandit and P. Sorensen:
Fourier Transform of data from STAR,
Phys. Rev. Lett. 95 (2005) 152301



low p_T ridge yield
STAR Preliminary



Large possible $\langle v_3^2 \rangle$ component in intermediate p_T data

Centrality dependence is similar to the low p_T ridge